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HUMID AREA SOILS AND MOISTURE FACTORS FOR IRRIGATION DESIGN

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HUMID AREA SOILS AND MOISTURE FACTORS FOR IRRIGATION DESIGN

Fred H. Larson[1], M. ASCE

Introduction

The purpose of this paper is to set forth the soil and moisture factors that have been used by the Soil Conservation Service of the U. S. Department of Agriculture in designing sprinkler systems in that part of the United States which includes New England, New York, Pennsylvania, New Jersey, Delaware, Maryland, and West Virginia.

The data presented have been found practical and workable but nevertheless must be used with some degree of caution because of local deviations from average conditions. This, however, is a caution that all who work with soils are accustomed to heeding.

Basic Data Needed by Farmers

Before beginning the design of a sprinkler system there are certain basic data that should be collected.

In the Soil Conservation Service it is our general policy to turn the job of designing over to the equipment company. Most farmers coming to us for assistance are co-operators of the Soil Conservation Districts, and we furnish the farmers with the basic soil and moisture data needed. These data can then be used by the equipment company for designing the system.

The data thus listed include the following:

(1) A conservation survey which shows slopes, erosion, soil, soil profile characteristics, crops and land use, as well as land use capabilities. This map is to scale.

(2) A sketch, to a larger scale, giving a few elevations and some pertinent distances.

(3) A description of the soil giving its infiltration rate, moisture holding capacity in terms of available moisture and any profile characteristics such as location of impervious layers or very droughty open layers.

(4) An estimate of the water supply including storage potential.

(5) An estimate of the kinds of crops to be grown and their daily consumptive use, irrigation interval, application per irrigation, and maximum permissible rate of application. The application and the rate give the number of hours to irrigate at each setting.

(6) A list of any operating conditions that the farmer deems pertinent such as (a) man-power needed, (b) number of hours available to irrigate each day, power source, cost limitation, etc.

(7) A short description of the enterprise such as: dairy, orchard, vegetable farm.

The attached sample inventory sheet was prepared by Gail Eley of the SCS and is used in the field.

The following discussion elaborates upon the above points that pertain

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particularly to the soil and moisture factors involved including the question of drouth and drouth periods.

The Need for Irrigation

Irrigation as a factor in agriculture in the humid eastern part of the United States has been recognized for at least 50 years, as indicated by bulletins published in those early years by the U. S. Department of Agriculture and the various states.

The value of irrigation stems from the fact that rainfall does not come at uniform intervals or in uniform amounts. Periods of deficient rainfall often occur in years when seasonal rainfall may be above average.

Associated with rainfall in a consideration of drouth is the amount of available moisture that can be stored in the soil.

Thus, in some seasons a sandy soil may be drouthy, while a silt loam may carry the plants successfully. A plant which has a high daily consumptive use (transpiration plus evaporation) will exhaust the soil moisture supply quickly and may show early signs of wilt.

Drouth periods and their frequency are thus not only a function of rainfall but also of unit moisture-holding capacity of the soil; root and/or profile depth; the plant's transpiration rate; and evaporation from the soil.

One method of determining drought frequency is to analyze rainfall records. A favorite method is to list all of the periods when no rain fell, or when only less than a specified amount fell. The results are interesting and are useful as a guide but are not conclusive because the method does not include the antecedent soil moisture condition or the plant and soil characteristics.

A better method is to use the so-called bank account method. In this system rainfall, irrigation, and original soil moisture are additive factors, and consumptive use and unavoidable losses are subtractive features.

Rainfall can be gotten from the records; irrigation can be added as it is applied.

Consumptive use can be measured by measuring the moisture in the root zone or by making an estimate.

For this latter purpose, consumptive use is usually calculated from either Thornthwaite's (1) or the Blaney-Criddle (2) method. Both methods are based on daily or average monthly temperatures and sunlight hours.

Using the bank account method, Thornthwaite has shown that from 3 to 9 2-inch irrigations are needed annually at Beltsville, Maryland (3).

The above factors are discussed in more detail later.

Tables I, II, and III give some of the average climatic factors usable in the Northeastern States. Local data, however, should be used for setting up local irrigation guides, a task which is being done as rapidly as possible by the Soil Conservation Service for all of the States of the Union.

To summarize:

(1) Irrigation in the humid East is needed to "iron out" the inequalities of rainfall amounts and frequency.

(2) Irrigation water need is a function of consumptive use and the moisture-holding capacity of the plant root zone.

(3) Drouth periods and frequency can be estimated by several methods. Table I shows that in every 2 years 3 absolute drought periods of 10 to 14 days' duration will occur.

(4) Total irrigation needs will run from 3 inches to 18 inches annually for many crops.

Irrigation Benefits

Irrigation benefits can be listed as follows:

(1) Puts a floor under the moisture level. This in turn requires the use of heavier applications of fertilizer and good soil management.

(2) Improves yields in most cases.

(3) Improves the quality of many crops.

(4) Insures early planting and more complete emergence of young seedlings.

(5) Provides insurance against drought.

Irrigation in the humid East presents some sharp contrasts. In dry years benefits in terms of yield and quality are high; in years of high rainfall benefits may be nil. Because of this, it is difficult to say that irrigation, as such, will give any fixed return, although averages over a few years are available for some crops.

In most cases the greatest benefits from irrigation occur only with high applications of fertility; other cases, notably the Arnot Pastures near Ithaca, New York, show that good management alone will almost double pasture yields and that irrigation adds only a small increment to the yield.

Farmers and the experiment stations generally show increased yields for most truck crops.

Drought and Economics

Because of the fact that rainfall is not uniform from year to year, the task of assembling economic data on the value of irrigation is a more difficult task than it is in the arid west. A year of high rainfall may not require irrigation or it may be a year of high rainfall with many drouth periods, thus requiring irrigation.

Comparative figures collected in any one year, or those comparing a year of irrigation against a year of no irrigation, do not mean much as the increases in yield may be nothing to many thousands of per cent. There is a great need for irrigation experiments covering a long series of years, such as now being conducted at the Geneva (N.Y.) Experiment Station on vegetables.

This experiment is set up for 10 years and correlates yields, weather and soils. Other experiments being conducted at Rutgers University of Connecticut, University of Massachusetts, Cornell University and other institutions, and by private enterprise should eventually furnish us with reliable long term data.

In the meantime interviews with farmers operating dairies, truck farms, orchards, and nurseries indicate that it is paying at least at the present level of farm prices.

Moisture Level and Yield

The benefits of irrigation appear to be greater at high moisture levels than at moderate or low levels. (By moisture level is meant amount of moisture depletion permitted in the entire root zone before irrigation is applied.)

The above, in terms of irrigation practice, indicates that irrigation should take place before the moisture level gets too low and that applications should wet the entire root zone.

This is a point that has not been fully grasped in the past but is rapidly coming to the fore. An unpublished compilation of numerous data made in 1951 by Dr. Thorne (4) of Utah State College indicates that high moisture levels out-produce lower moisture levels. For many years irrigation experts recommended to farmers that they should irrigate when 70% of the moisture

in the root zone was depleted; experience soon showed that western farmers, seldom if ever, let moisture get below a 50% level. Because most of the cost of a sprinkler system is in the form of capital charges, it seems that it would be foolish to jeopardize a crop in order to save the $2.00 to $3.00 of out of pocket expense that it takes to apply one acre inch of water.

Long time data with thoroughgoing measurements are needed to resolve the question of profits. In the meantime farmers who think of themselves as irrigation farmers seem to be satisfied with their systems.

Crop, Soil, and Moisture Factors for Design

To properly design a system, basic data are needed on:

A. Climate

1. Drouth.
2. Rainfall.
3. Temperature.
4. Daylight hours.
5. Growing season.

B. The soil and soil moisture

1. Moisture needs.
2. Infiltration rate.
3. Field capacity and wilting point supply.
4. Moisture availability.
5. Water movement.

C. The plant and soil moisture

1. Consumptive use.
2. Determination of consumptive use.
3. Moisture extraction pattern.
4. Rooting depth.

Data for the above are tabulated on a Data Sheet, copy of which is appended.

A. Climate

As stated above, temperature and absolute drouth periods have been indicated in Tables I and II. Table III gives daylight hours in percent for the states previously mentioned.

Consumptive use has been studied in relation to such factors as temperature, daylight hours, humidity, wind velocity, etc., by various investigators. From a practical standpoint, it appears sufficient to use only the climatic factors of daylight hours and temperature.

B. Soil and Soil Moisture

1. The natural source of most soil moisture is rainfall. This is often supplemented by the artificial application of water. The annual needs of most plants lie between 15 and 22 inches. Not all of the rain that falls is available to the plant. Some runs off, and some is lost as deep percolation. The effective rainfall thus becomes the rainfall that can infiltrate into the soil and remain in the root zone until needed.

2. Infiltration rates vary with vegetal cover, tillage practices, moisture conditions in the soil, texture, depth of profile, etc. The usual pattern or curve indicates a high initial rate which falls off rapidly (usually in about an hour) to a basic infiltration rate.

   This basic infiltration rate for various soils, cover conditions, and slopes is shown in Table IX. These rates are operating maximums and should be reduced for soils that have been poorly managed and,

consequently, have poor structure. Subsoils of slow permeability have a material effect on the infiltration rates.

3. Field capacity and wilting point. Soil moisture has been classified into 3 main categories, depending upon its availability to and effect upon the plant.

   Soils consist of mineral and organic particles of various sizes and shapes. Between these particles are open spaces filled with air or water.

   According to Israelson, "Irrigation Principles and Practices", the water in the soil is divided as follows:

   "a. Hygroscopic water is on the surface of the soil grains and is not capable of movement through the action of gravity or capillary forces.
   "b. Capillary water is that part in excess of the hygroscopic water which exists in the pore space of the soil and which is retained against the force of gravity in a soil that permits unobstructed drainage.
   "c. Gravitational water is that part in excess of the hygroscopic and capillary water which will move out of the soil if favorable drainage is provided.

   There is no precise boundary or line of demarcation between these 3 classes of soil water."

   The upper limit of capillary moisture is called field capacity; the lower limit is called the wilting point or range. This water (between field capacity and wilting point) is called the "available moisture", because it represents the amounts available to plants.

   Field capacity is measured in the field and represents the moisture in the soil 24 to 48 hours after irrigation. Wilting point is the point at which dwarf sunflowers permanently wilt.

   The above are expressed usually in percent of dry weight. (See Table VI for typical examples.) They are also measured in atmospheres. This represents the force needed to remove the water. Wilting point is taken as 15 atmospheres — field capacity at 0.1 atmosphere.

4. Moisture availability. As pointed out before, moisture availability is governed by:

   a. The range between field capacity and wilting point. This varies with each soil. Tables VI and VIII give data for various textures. These figures probably apply to 80 percent of the soils to be irrigated. Local exceptions may be very important.
   b. The characteristic of each horizon. A soil containing 2 feet of sand (at 0.75 inch to the foot) and 2 feet of silt loam (at 1.75 inches to the foot) will contain 5.0 inches of available (or capillary) moisture. (See Table VIII.)
   c. The usable depth of the soil. This will be governed by root zone depth. Root zone depth, in turn, may be governed by (1) an impervious layer; (2) a high water table; or (3) by a droughty, open soil.

      Thus, a normal 4-foot root zone may be only 2 feet in a shallow soil. (See Table VII for normal root zones.)
   d. Moisture tension. Investigations indicate that moisture is more readily available at low tensions than at high. With field capacity at 0.1 atmospheres and wilting point at 15 atmospheres, moisture is more

readily available to the plant at, say, 1 atmospheres than at, say 10 atmospheres.

This indicates the importance of wetting the entire root zone frequently to keep a high moisture (low tension) level.

5. Water movement. The initial surface penetration of rain or sprinkler irrigation water into the soil is called infiltration. The infiltration rate of a soil decreases with time. The initial rate may be as much as 10 inches per hour. As the rain continues, the rate becomes progressively less. At the end of one or 2 hours the "basic" infiltration rate has been established. Beyond this time, the infiltration rate decreases so slowly that it is of no importance. (See Table IX for "basic" rates.)

   The moisture entering the soil must fill the soil to a point above field capacity before downward movement starts. The water will then move downward to a point where the infiltrated water will just fill the intervening soil profile to field capacity.

   For instance (see Chart II), if a soil is at wilting point, a 4.0-inch application will fill a silt loam to a 2.0-foot depth if the available (capillary) moisture is 2.0 inches per foot, with the soil at wilting point.

   If the soil is at a moisture point midway between field capacity and wilting point, then a 4-inch application for the above soil would penetrate 4.0 feet (1 inch per foot).

   In most soils the extent of depletion is not uniform, nor is the available moisture uniform throughout the profile. In this case, each horizon must be analyzed and the amount of moisture needed to replenish each horizon determined and then added together.

   If an insufficient amount of water is applied, a relatively dry zone may develop in the intermediate or lower horizons. In the extreme case, these horizons may approach wilting point. However, Harrold (5) has shown that, as the moisture tension increases, the rate of extraction decreases so that finally the extraction rate in all portions of the profile tend to approach uniformity.

C. The Plant and Soil Moisture

Practically all types of farm crops are irrigated in North Atlantic States, with the major emphasis on truck crops. Grasses, legumes, grapes, and tobacco are also irrigated in many areas. The major factors effecting sprinkler design are:

a. At what rate (consumptive use) does the plant use water?
b. Where does this water come from? Or, what is the moisture extraction pattern by the roots?
c. What is the effect of insufficient application of moisture?

1. Consumptive-Use (Evapo-transpiration). This term is defined by Blaney and Criddle as "the sum of the volumes of water used by the vegetative growth of a given area in transpiration and building of plant tissue and that evaporated from adjacent soil, snow, or intercepted precipitation on the area in any specified time, divided by the given area. If the unit of time is small, the consumptive use is expressed in acre-inches per acre or depth in inches."

2. Determination of Consumptive Use. Consumptive use by a crop is best determined directly by measuring the rate at which moisture is extracted from the entire root zone. (Table VIII.) Often it is impractical to do

this. This has resulted in the use of estimates based on climatic factors such as wind, temperature, daylight hours, evaporation, humidity, etc. Consumptive use figures are determined for a growing season for a month or for weeks or days.

From the standpoint of reservoir capacity, seasonal figures are useful. In sprinkler design, we are concerned with a short period, usually less than 2 or 3 weeks, corresponding to the irrigation interval.

Consumptive use is a measure of the moisture to be replaced and is equal to the moisture extracted from the soil. Methods of determining this for design and for operations are discussed as follows:

In setting up criteria for sprinkler system design, we have a need for data on consumptive use. This is gotten in 2 ways:

a. From experimental data collected by experiment stations.
b. By calculation with some tested method. This test consists of comparing computed values with values determined at various experiment stations and projects.

After many trials, Blaney, Criddle (2), Thornthwaite (1), and others seem to be agreed that temperature and daylight hours are the prime factors and have worked out methods for determining consumptive use values.

The Blaney-Criddle method has been used by the Soil Conservation in the West. It is satisfactory for the Atlantic area if it is adjusted slightly. This method was worked out to give seasonal or monthly quantities. It has been used to give daily or short period figures by taking the monthly figures and breaking them down into daily figures. Experience shows that this breakdown gives short period values that are too low. Availability of surface moisture and short periods of high temperatures account for this.

Table II shows that average temperatures run as much as 7° under the high average monthly. A correction factor for short period irrigation is shown in Chart III. This factor is tentative but seems to be fairly accurate although conservative.

The multipliers to use are (1) average monthly temperature, (2) percent of daylight hours, and (3) a "K" (crop) factor set up for each crop and the correction factor for length of period as shown in Chart III.

The above factors are shown in Table II (temperature on a generalized basis by areas), Table III (daylight hours), Table IV, "K" (crop) factors, and Chart III (irrigation interval correction). To get daily figures, the above must be divided by the number of days in the month. Table V gives these daily values for the month of July.

In operating the system, consumptive use must be determined by the farmer because this is the amount of moisture to be replaced. This can be done in 3 ways:

1. By measurement with tensiometers, Buoycous, or other blocks, or testing the soil moisture by drying and weighing.
2. Another method is by a "feel" test. In this method the farmer "feels" the soil and estimates the amount to be replaced. For this, he needs a soil auger. Criteria to use in making this test are available but are not shown in this paper because of space limitations.
3. Another practical method is to check the soil the day after irrigation by examining the soil profile. If the previous day's irrigation

didn't wet the entire root zone, then not enough water was applied, and today's irrigation would have to be longer. If too much water was applied, today's irrigation will be shorter.

3. Moisture extraction pattern. An understanding of the manner in which moisture is extracted from the soil is important.

Assume that in the spring the soil column is filled to field capacity. As the plant grows, moisture is extracted throughout the root zone. In the upper 6 inches, part of this is evaporation and part is transpiration. Below the 6 inches, the extraction is mainly the result of root action, except for a small amount of downward drainage, which is usually ignored.

Moisture extraction measurements at fairly high moisture levels show the following: (6)

Depth*	% Extraction	Ratio	Crop
0-25%	.40	1.0	Average for alfalfa,
25-50%	.30	0.83	potatoes, sugar
50-75%	.20	0.54	beets, corn,
75-100%	.10	0.32	wheat, etc.

*In terms of percent of the root zone depth. On alfalfa, 25 percent may be 1.5 feet; on a truck crop with 2-foot root zone, it may be 6 inches.

Some variations may be found in various plants, but the above is a good average at high moisture levels.

The above table is useful in estimating the depth to which a given application of water will go or in estimating the total extraction when only a portion of the profile is examined.

If a plant has extracted 2 inches of moisture in a given period, then we can say that it came from the different portions of the root zone proportionately, as shown above.

Table VII gives data on rooting depths. Local data should be used where these rooting depths appear to be affected by local factors.

How to Irrigate.

The basic factors influencing crops, soil, and moisture were set forth above. This section will deal with criteria for determining the answer to the following questions:

A. How much water should be applied?
B. How fast?
C. When to begin irrigation?
D. Effect of fixed interview of irrigation?

A. How much water to apply:

The amount of water to apply should be enough to fill most of the entire root zone to field capacity. Some examples of this were worked out under "Moisture Extraction." If an insufficient amount of moisture is applied, some of the lower reaches of the root zone will become progressively drier. If this continues, damage may result to the plant, and quality and quantity will be reduced. The importance of this is hard to over-emphasize. A 1-inch application of moisture will often only go a fraction of a foot into the soil. (See Chart II.) It is thought that some of the failures to show benefits on irrigated pastures may be due to high moisture tensions at the lower parts of the root zone because of dryness.

In addition to replacing the depleted moisture, an allowance must be made for efficiency of application. Some of the water is lost in the air, some due to uneven distribution resulting in deep percolations in spots, and some due to run-off. About the highest efficiency to be expected is 80%. Efficiency is corrected for by adding a percentage to the time of application. (See Table IX.)

B. Rate.

The rate of application must be less than the infiltration rate. (See Table IX.) In some cases drop size is a factor that may cause injury to plants or surface puddling. This is regulated by selecting the proper type of sprinkler. (See Table X.) Soils with very low intake rates often cannot be effectively irrigated.

C. When to begin irrigation?

The simplest case occurs when the farmer can do all of his irrigating in one day. In this case, he determines the amount of moisture extracted, corrects for efficiency of application, and applies the quantity needed.

If he has computed the amount extracted on the basis of "feel" charts then a quick look at Table VIII, will give him the moisture, per foot, to apply his extraction percentages against. Thus, a 50 percent extraction on a 3-foot silt loam holding 2 inches of moisture means that $(2 \times 3 \times .50) = 3$ inches has been used by the plant and must be replaced.

If the farmer has a large number of tracts and irrigates one or more a day, the moisture level in the last tract may be at or near the wilting point by the time the irrigator gets to it. This means that the irrigator must start soon enough so that he can get to the last tract in time.

A practical basis for this determination is as follows:

Start irrigation on tract 1 when 40 percent of the moisture in the root zone is depleted. Get to the last tract when 80 percent or less of the moisture is depleted.

Example: 1

Crop - Potatoes - "K" factor (See Table IV)
Average monthly temperature - 70^0
Latitude - 40^0
Soil - silt loam

Consumptive use is .15 inch per day (selected from Table V).
Correct this by estimating a 14-day irrigation interval.
Multiply .15 by 1.12 (see Chart VI) = .168 inch per day.
Moisture-holding capacity for a 3-foot silt loam is 2 inches per foot (Table VIII), or a total of 6 inches.
Depletion at 40 percent will equal 2.4 inches. Depletion at 80 percent will equal 4.8 inches.
Difference = 4.8 inches - 2.4 inches = 2.4 inches.

Irrigation interval $= \frac{2.4''}{.168} = 14.2$ days

Average application will equal $\left(\frac{2.4'' + 4.8''}{2}\right)$

At 70 percent efficiency = 5.1 inches.

Example: 2

If the moisture-holding capacity for a 3-foot coarse sandy loam is 0.75 inch per foot and the total is 2.25 inches, then -

Depletion at 40% = .9"
Depletion at 80% = 1.8"

Consumptive use (Table V and Chart III) will be (based on a 6-day interval) =.15 x 1.25 = .188 inch.

Irrigation interval = $\frac{1.8 - .9}{.188} = \frac{.9}{.188}$ = 4.7 days (say 5 days)

Average application per irrigation = $\frac{1.8 + .9}{2} = \frac{2.7}{2} = 1.35"$

At 70 percent efficiency = $\frac{1.35}{.70} = 1.93"$

It will be noted in the above that at the 80 percent depletion (20 percent moisture level) much of the root zone will have a high moisture tension.

If irrigation continues for a second round, then the average application per irrigation will be less because the initial waiting period is eliminated.

In the first example it will now be $\left(\frac{14.2 \text{ days} \times .168}{.70}\right)$ = 3.4 inches.

In the second example it will now be $\left(\frac{5 \times .168}{.70}\right)$ = 1.20 inches.

In the above examples it was shown that: Sprinklers in the humid areas must be designed so that water can be applied to all the tracts before growth stops or is retarded.

From a practical standpoint, this was set at a 60 percent moisture level for the first day's irrigation and 20 percent moisture level for the last day's irrigation on the first round; or an average of 40 percent moisture level. (In other words, 40 percent extraction for the first tract, 80 percent extraction for the last, or an average 60 percent extraction.)

In the examples 1 and 2 above:

On the silt loam, start irrigating in $\frac{2.4}{.168}$ = 14.2 days.

On the coarse, sandy loam, start irrigating in $\frac{.9}{.168}$ = 5.3 days.

D. Effect of a fixed interval of irrigation.

In Example 1 (silt loam), it was shown that the irrigation interval was 14.2 days, or say 14 days, and later we showed that the first irrigation would occur 14.3 days after drought started. Thus, about 28 days would elapse before the last tract was irrigated.

Often in this kind of case the farmer may, sensibly, prefer to start earlier or do more tracts per day.

Example 3: Farmer wishes to irrigate every 9 days (or 7, etc.).

Consumptive use is .15" x 1.19 (Table V and Chart III) = .79 per day.
If the first irrigation starts at 9 days, then:
Moisture to replace = 9 x .179 = 1.6"
If there are 9 tracts, depletion at the last tract will be

2 x 1.6 = 3.2"

$$\text{Average application} = \frac{1.6 + 3.2}{2} = \frac{4.8}{2} = 2.4$$

$$\text{At 70\% efficiency} = \frac{2.4}{.70} = 3.4''$$

On the second round of irrigation, the application will be

$$\frac{9 \times 179}{.70} = \frac{1.61}{.70} = 2.3''$$

Conclusions

1. The first round of irrigation has the job of compensating for the period just prior to irrigation during which no water was applied. The applications are therefore heavier.
2. The fixed interval ("D" above) method appears more practical for medium or heavy soils. The "last tract" analysis is a necessity for light, shallow, droughty soils.
3. From a practical standpoint, a maximum irrigation interval of 10 to 14 days appears desirable. Shorter intervals will be dictated by the droughthiness of the soil or by the wishes of the farmer.
4. The quantity of water to apply should never be less than the consumptive use for the irrigation interval, plus an allowance for efficiency. This statement includes small, light, frequent irrigation for early spring crops or plant emergence.

Other Factors Affecting the Irrigation System

Other factors affecting irrigation design are:

A. Water Supply.
B. Effect of rain.
C. Farmer factors.
D. Soil management and water disposal.
E. Topography and configuration.

A. Water Supply

The availability of a dependable water supply is a prime consideration. In many areas of this region, the demand for water exceeds the supply. In some areas stream flow diminishes to a critical point during dry periods.

In some areas water can be obtained from wells. In other areas it can be pumped from dugouts, which are replenished by underground flow.

Sources of irregular supply can often be helped by reservoirs which conserve flows that might otherwise be lost.

A rough knowledge of the water needed is always helpful in making a preliminary analysis.

A continuous flow of 4 to 8 g.p.m. (average about 5) is needed to irrigate one acre. If irrigation takes place for a fraction of a day, then the above figure must be increased proportionately.

An annual supply of one acre-foot per acre is needed if all the water is to come from a reservoir. If the reservoir is replenished between irrigations, then available storage can be less than one acre-foot per acre to be irrigated.

B. Effect of Rain

In arid regions, the problem of rain occurring after the land has been irrigated happens but seldom and hence the probability can be ignored.

In the humid East, it often happens that rain occurs after the land has been irrigated. If the irrigation brought the soil profile up to field capacity, a study of Table VI will show that there is still considerable room for gravitational water. On sand, this amounts to 2.7 inches per foot; on clay, it is 0.6 inch per foot. On this basis, it can be said that the danger of damaging run-off is slight. But at this point, another factor enters. Infiltration is less at the higher moisture levels. Brill, at New Brunswick, New Jersey, has shown that irrigated land erodes more severely than unirrigated land, and run-off is greater.

The suggestion is often made that the soil profile should not be filled to field capacity, thereby reserving part of the storage for rain. If 20 percent is reserved, we see on Table VII for a 4-foot depth that the amount provided would be about .4 inch on a sandy soil and .8 inch on a clay loam. This would be of some value on a clay loam where the gravitational water storage is small, but would be of little value on a sandy soil. In addition, failure to fill the profile (root-zone) to field capacity would reduce the benefits of irrigation.

C. Farmer Factors

This includes:

1. Hours of operation. How many acres a day can be irrigated?
2. Labor supply.
3. What kind of power is available?
4. What can he afford to spend? Systems around 30 acres cost from $100 to $125 per acre and more for small tracts. Annual out-of-pocket costs run up to $2.50 per acre-inch. Capital costs run about $15 per acre.

D. Soil Management

The application of irrigation water to the land in the humid East (and the arid West, too) brings out some problems that require consideration. On the silt loam soils of the experiment station at New Brunswick, irrigated soils have compacted, resulting in lower infiltration and permeability rates, reduced aeration, occasional low yields, etc. It is not known if this will occur on other soils. On the same soils, erosion increases with irrigation.

Thus, it is obvious that irrigation, resulting in greater demand on the soil, requires more attention to good soil management practices.

The need for safe disposal of surplus irrigation water (which should be nonexistent under good irrigation management) and excess rainfall is obvious. Irrigation should be practiced only on lands where the possibility of producing a water-logged condition is remote. Soils to be avoided would be those shallow soils, heavy textured, where surface and subsurface drainage is poor.

The question of fertilizer is important. It is almost axiomatic that the irrigation makes it mandatory to use heavier applications of fertilizer to get full return on the water used.

A farmer anxious to increase yields should first try increased use of fertilizer, good soil management, and improved varieties. Much can be gained in this way before spending money on irrigation. Irrigation, of course, will usually boost these yields somewhat.

E. Topography and Configuration.

Key elevations are needed on the fields to be irrigated. Detailed data are needed at the pump site; on the rest of the field, a few critical elevations to the nearest foot are all that is needed.

The shape of the tract greatly influences design and hence the cost. The cheapest layout is a square with pumping plant in the middle of the square; long, narrow tracts can require a lot of main line, thus running up the cost. In any event, an accurate map is needed.

REFERENCES

(1) Thornthwaite, C. W. "An Approach Toward a Rational Classification of Climate." Geographical Review, Vol. xxxVIII, No. 1, 1948.

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(3) Thornthwaite, C. W. "Evapo-Transpiration in the Hydrologic Cycle", Physical and Economic Foundation of Natural Resources Vol. II House of Representatives, Interior and Insular Affairs Committee, 1952.

(4) Thorne, D. W., Mimeo. paper presented at Utah State College, 1951.

(5) Harrold, Lloyd H. Unpublished data from Coshocton, Ohio, North Appalachian Experimental Watershed.

(6) Shockley, Dale. Unpublished data on moisture extraction in root zone under irrigation.

UNITED STATES DEPARTMENT OF AGRICULTURE
SOIL CONSERVATION SERVICE

SPRINKLER IRRIGATION DATA SHEET

Date ______________________ State ______________________

Farmer's Name ______________________ County ______________________

Data Obtained By ______________________ SCD ______________________

1. Design Area ____________ Acres in Field: a. ________ , ________ acres;

   b ________ , ________ acres, c. ________ , ________ acres

2. Crops Planned to Irrigate and Peak Consumptive Use (CU) in Inches Per Day:

   Crop ________ , CU ____ ; Crop ________ ; CU ____ ; Crop ________ ; CU ____ ;

   Orchard ________ , CU ____ : Spacing of trees ________ ft x ________ ft.

3. Soils:

   a. Soil texture and profile description ______________________

   ____

   b. Water-holding capacity (WHC) of soil:

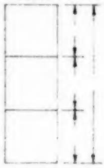
   Total available moisture (TAM) equals the rooting zone depth times the water-holding capacity   WHC ____"/ft.

   ____"/ft.

   ____"/ft.

   (______ x ______) = ________ inches

Soil Profile
TAM



Horizons and Depths

   c. Intake rate ________ inches per hour

   d. Water replacement per irrigation, first cycle, ______________ acre-inches per acre

   e. Irrigation depth ________ inches

4. Water Supply:

   a. Creek ________ GPM; River ________ GPM; Pond ________ acre-feet total storage;

   Lake ________ acre-feet storage; Deep well ________ GPM: Other ________

   b. How is pond discharged ______________________

   c. Measured ________ GPM recharge   Date ______________

5. Operation Data:

a. Will irrigate ____________ hours per day, including moving time

b. Irrigation will begin ____________ (DATE) and end about ____________ (DATE)

c. Irrigation interval ____________ days

6. Profile of Pump Site:

a. Height of pump above water surface ____________ feet

b. Horizontal distance from water to pump ____________ feet

c. Height of highest point to irrigate above pump ____________ feet

7. Plot Plan:

a. Topography: Show spot elevations of field corners and highest and lowest elevations to be irrigated relative to water surface.
If area will be contour strip cropped, show all strip boundaries accurately.

b. Attach map showing shape and dimensions of field.

Past history of field:

TABLE I

NUMBER OF EVENTS OF INDICATED DURATION WHEN NO RAIN FELL

Station	Yrs. Period	Days 10 - 14	Days 15 - 19	Days 20 - 24	Days 25 - 29	Days 30 +
Bangor, Me.	25	36	8	4	0	0
Greenville, Me.	30	27	5	0	0	0
Portland, Me.	30	34	7	2	1	0
Burlington, Vt.	30	26	5	1	0	0
Concord, N. H.	30	46	14	3	0	0
Boston, Mass.	30	48	15	3	2	0
Pittsfield, Mass.	25	38	10	2	0	0
Hartford, Conn.	30	44	10	4	1	0
Albany, N. Y.	30	31	7	3	1	0
Buffalo, N. Y.	30	48	12	3	0	0
Canton, N. Y.	30	35	3	0	0	0
Syracuse, N. Y.	30	32	3	2	1	0
New York, N. Y.	30	41	12	3	2	0
Somerset, Pa.	30	38	1	1	0	0
Bethlehem, Pa.	30	47	13	3	1	1
Indiana, Pa.	12	19	4	0	0	0

U. S. Department of Commerce

Weather Bureau

1922-1951 and 1926-1951

April 1 through October 31

Note: An analysis, based on days when 0.15" or less of rain fell per day, shows 3 to 4 times as many events of 10-14 days' occurrence, as shown above. Drought frequencies thus probably lie between these two extremes.

TABLE II

MONTHLY TEMPERATURES

New England

Average Monthly Temperatures

April	48.5 °F
May	56.6
June	61.6
July	69.4
August	65.8
September	60.4
October	51.9

Highest Average Monthly Temperatures

Month	Year	North	Year	South
October	1947	53.7°F	1947	57.7°F
September	1934	62.0	1930	66.3
August	1937	71.0	1937	73.3
July	1921	72.1	1949	74.7
June	1930	67.2	1930	69.6
May	1911	59.9	1948	61.4
April	1921	47.3	1945	51.2

New York

Average Monthly Temperatures

April	44.3 °F
May	56.1
June	65.1
July	69.8
August	67.7
September	61.2
October	50.2

Highest Average Monthly Temperatures

Month	Year	Temp.
October	1947	57.0 °F
September	1921	65.5
August	1947	72.4
July	1921	74.9
June	1949	70.1
May	1911	62.9
April	1921	51.9

2-Table II-Monthly Temperatures

Maryland and Delaware

Average Monthly Temperatures

	Md.	Del.
April	52.3°F	52.6°F
May	62.8	63.2
June	70.8	71.5
July	75.2	76.1
August	73.4	74.4
September	67.5	68.5
October	56.4	57.6

Highest Average Monthly Temperatures

Month		Year	Md.	Del.
October		1919	62.3°F	63.3°F
September		1930	72.9	73.8
August		1900	78.8	78.7
July	1949	1901	78.8	80.2
June	1943	1925	76.5	77.5
May	1944	1944	68.4	67.7
April	1921	1921	58.0	58.5

New Jersey

Average Monthly Temperatures

April	49.8°F
May	60.6
June	69.1
July	73.9
August	72.0
September	65.9
October	54.9

Highest Average Monthly Temperatures

Month	Year	Temp.
October	1947	60.4°F
September	1931	70.5
August	1900	76.3
July	1944	78.0
June	1943	74.2
May	1944	65.3
April	1921	56.3

3-Table II-Monthly Temperatures

Pennsylvania

Average Monthly Temperatures

April	48.6°F
May	59.6
June	68.1
July	72.1
August	70.3
September	64.0
October	52.7

Highest Average Monthly Temperatures

Month	Year	Temp.
October	1947	58.6°F
September	1931	69.1
August	1900	75.0
July	1901	76.4
June	1943	73.0
May	1944	65.6
April	1921	55.3

West Virginia

Average Monthly Temperatures

April	51.9°F
May	61.8
June	69.8
July	73.1
August	71.8
September	66.2
October	54.9

Highest Average Monthly Temperatures

Month	Year	Temp.
October	1919	62.3°F
September	1900	71.1
August	1918	76.0
July	1934	77.5
June	1943	75.0
May	1896	68.3
April	1896	57.7

TABLE III

MONTHLY DAYLIGHT HOURS IN PER CENT OF TOTAL ANNUAL DAYLIGHT HOURS - LAT. 37° TO 47°

(FOR USE IN CALCULATING IRRIGATION REQUIREMENTS)

Month	37°	38°	39°	40°	41°	42°	43°	44°	45°	46°	47°
January	6.928%	6.869	6.809	6.746	6.680	6.614	6.544	6.470	6.396	6.321	6.238
February	6.808	6.776	6.742	6.709	6.674	6.639	6.606	6.562	6.524	6.483	6.441
March	8.322	8.315	8.313	8.306	8.296	8.290	8.283	8.274	8.266	8.258	8.248
April	8.853	8.875	8.900	8.921	8.949	8.975	9.001	9.031	9.059	9.088	9.120
May	9.848	9.900	9.950	10.004	10.060	10.117	10.178	10.240	10.306	10.369	10.439
June	9.882	9.945	10.009	10.078	10.146	10.218	10.294	10.372	10.450	10.535	10.625
July	10.047	10.106	10.168	10.230	10.296	10.361	10.430	10.505	10.578	10.655	10.738
August	9.449	9.483	9.519	9.559	9.598	9.637	9.678	9.720	9.763	9.809	9.854
September	8.384	8.390	8.396	8.404	8.412	8.418	8.423	8.429	8.437	8.443	8.452
October	7.844	7.823	7.796	7.769	7.743	7.716	7.689	7.661	7.629	7.600	7.568
November	6.892	6.843	6.791	6.739	6.683	6.627	6.571	6.511	6.450	6.385	6.317
December	6.742	6.675	6.606	6.536	6.463	6.389	6.308	6.226	6.140	6.053	5.960

TABLE IV

TENTATIVE
CROP FACTOR "k" FOR
THE BLANEY-CRIDDLE CONSUMPTIVE
USE FORMULA
FOR NORTH ATLANTIC AREA

K = 0.55	K = 0.65	K = 0.75
Onions	Bluegrass	Ladino Clover
Radishes	Blueberries	White Clover
Lettuce	Potatoes	Sweet Corn
Spinach	Beans (Snap)	Field Corn
Strawberries	Orchard Grass	
Cabbage	Red Clover	Alfalfa
Celery	Peas	Orchard with cover
Cucumbers	Peppers	
Beets	Gladioli	Vineyard with cover
Carrots	Small grain	
Squash	Birdsfoot Trefoil	
Beans (Dry)	Bromegrass	
Asparagus	Orchard Grass	
Broccoli	Tall Fescue	
Cantaloupes	Sweet Clover	
Pumpkins	Vineyard	
Winter Grain	Brambles	
	Orchard	
	Tomatoes	
	Tobacco	

TABLE V

Temp. (t)	Lat.	p	t x p = f	.55	.60	.65	.70	.75	.80	.85
				Crop Factors "k" (Daily)						
62°	44°	10.505	6.52	.117*	.123	.137	.143	.156	.170	.176
	45	10.578	6.56	.118	.125	.138	.144	.157	.171	.177
64	44	10.505	6.72	.121	.128	.141	.148	.161	.175	.181
	45	10.578	6.78	.122	.129	.142	.149	.163	.176	.183
	47	10.738	6.88	.124	.131	.144	.151	.165	.179	.186
66	42	10.361	6.84	.123	.130	.144	.150	.164	.178	.185
	43	10.430	6.89	.124	.131	.145	.152	.165	.179	.186
	44	10.505	6.94	.125	.132	.146	.153	.166	.180	.187
	45	10.578	6.98	.126	.133	.147	.153	.168	.181	.188
	46	10.655	7.04	.127	.134	.148	.155	.169	.183	.190
	47	10.738	7.09	.128	.135	.149	.156	.170	.184	.191
68	38	10.106	6.89	.124	.131	.145	.152	.165	.179	.186
	40	10.230	6.96	.125	.132	.146	.153	.167	.181	.188
	42	10.361	7.05	.127	.134	.148	.155	.169	.183	.190
	44	10.505	7.14	.129	.136	.150	.157	.171	.186	.193
70	38	10.106	7.07	.127	.134	.148	.155	.170	.184	.191
	40	10.230	7.16	.129	.136	.150	.157	.172	.186	.193
	42	10.361	7.25	.131	.137	.152	.159	.174	.189	.196
	44	10.505	7.35	.132	.140	.154	.162	.176	.191	.198
	45	10.578	7.40	.133	.141	.155	.163	.178	.192	.200
72	38	10.106	7.28	.131	.138	.153	.160	.175	.189	.197
	40	10.230	7.37	.133	.140	.154	.162	.177	.192	.199
	42	10.361	7.46	.134	.142	.157	.164	.179	.194	.201
	43	10.430	7.57	.136	.144	.159	.166	.182	.197	.204
74	38	10.106	7.47	.134	.142	.157	.164	.179	.194	.202
	40	10.230	7.57	.136	.144	.159	.166	.182	.197	.204
	41	10.296	7.62	.137	.145	.160	.168	.183	.198	.206
76	38	10.106	7.68	.138	.146	.161	.169	.184	.200	.207
	40	10.230	7.78	.140	.148	.163	.171	.187	.202	.210

Chart of July Daily Consumptive Use Factors for
Use in Blaney-Criddle Method

Temp. = Average monthly temperature.

Lat. = Latitude.

p = Percent of yearly daylight hours occurring in July.

t x p = Monthly consumptive use factor.

k = Crop factor which varies by crops.

* = Figures = t x p x k divided by 31 days = daily consumptive use factor.

Note: Add 10 to 15 percent for hottest months if average monthly temperature is used.

TABLE VI

Physical Properties of Soils**

Soil Type	Dry Wt. of Soil Lbs. Per Cu. Ft.	Voids %	Inches of Water in 1 ft. of Saturated Soil	Irrigation Factors				Available Moisture	Drainage Factor
				Field Capacity % Wt.	Field Capacity Inches	Wilting Point % Wt.	Wilting Point Inches	Inches Per Ft.	Gravitational Water Per Foot of Depth
Sand	105	30.5	3.7	4.9	1.0	2.5	0.5	.5*	2.7
Sandy loam	100	34.0	4.1	10.6	2.0	6.5	1.25	.75	2.1
Sandy loam	95	37.5	4.5	15.9	2.9	9.0	1.65	1.25	1.6
Sandy silt loam	90	41.0	4.9	21.2	3.7	12.6	2.2	1.5	1.2
Silt loam	85	44.5	5.4	26.8	4.4	16.0	2.65	1.75	1.0
Silt loam	80	48.0	5.8	32.7	5.0	19.6	3.0	2.00	0.8
Clay loam	75	51.5	6.2	38.5	5.5	23.5	3.5	2.00	0.7
Clay	70	55.0	6.6	44.6	6.0	31.2	4.2	1.8	0.6

* See Table VIII for estimates of total available moisture ranges for various depths of root zone.

** Adapted from "Drainage and Flood Control Engineering" by Pickels.

See Chart I for chart illustrating kinds of soil moisture.

TABLE VII

EFFECTIVE ROOT DEPTHS FOR VARIOUS CROPS (BASED ON ROOT HABITS IN DEEP AND WELL-DRAINED SOIL)

Very Shallow Down to 15"	Shallow Down to 24"	Moderately Deep Down to 32"	Deep Down to 40"	Very Deep More Than 40"
Onions	Potatoes	Cabbage	Asparagus	Alfalfa
Radishes	Celery	Broccoli	Sweet corn	Orchards
Lettuce	Peas	Brussels sprouts	Field corn	Vineyards
Spinach	Red clover	Cucumbers	Birdsfoot trefoil	Brambles
Strawberries	Timothy	Cantaloupes	Winter grains	
Ladino clover	Gladioli	Carrots	Sweet clover	
White clover		Tomatoes	Nursery stock	
Bluegrass		Beets	Artichokes	
Blueberries		Squash	Lima beans	
		Pumpkins	Parsnips	
		Snap beans	Watermelons	
		Dry beans		
		Spring grains		
		Bromegrass		
		Orchard grass		
		Tall fescue		
		Sweet potatoes		
		Tobacco		
		Cauliflower		
		Chard		
		Turnips		
		Peppers		
		Eggplant		
		Mustard		

Note: From recommendations for irrigation in New York State by 1952 Irrigation Conference at Cornell University, Ithaca, N. Y.

TABLE VIII

ESTIMATED SOIL MOISTURE TO BE REPLACED PER IRRIGATION

Soil Texture and Profile Description	Total Soil Moisture Capacity for Plant Use - Inches Per Foot Depth**	*Soil Moisture to Replace Per Irrigation for 2', 4', and 6' Root Zone or Soil Depth (Ac. in./ac.)		
		2 Feet	4 Feet	6 Feet
1. Coarse, sandy soils, uniform in texture to 6'	0.50 - 0.75	.4 - .6	.8 - 1.2	1.2 - 1 8
2. Coarse, sandy soils over more compact subsoils	0.75 - 1.0	.6 - .8	1.2 - 1.6	1.8 - 2.4
3. Sandy loam soils uniform in texture to 6'	1.25 - 1.50	1.0 - 1.2	2.0 - 2.2	3.0 - 3.4
4. Sandy loam soils over more compact subsoils	1.25 - 1.75	1.0 - 1.4	2.0 - 2.8	3.0 - 4.2
5. Silt loam soils uniform in texture to 6'	1.75 - 2.25	1.4 - 1.8	2.8 - 3.6	4.2 - 5.4
6. Silt loam soils over more compact subsoils	2.00 - 2.25	1.6 - 1.8	3.2 - 3.6	4.8 - 5.4
7. Heavy textured clay or clay loam soils	1.8 - 2.0	1.4 - 1.6	2.8 - 3.2	4.2 - 4.8

* Based on irrigating when 60% of the moisture has been extracted from the top 25% of the depth or 40% from the total root zone.

For plots irrigated after the first day, add a quantity of water equal to the consumptive use for the time interval elapsed. Thus, on plot 1, apply say 3.6"; on plot 5 (4 days later), add 4 times the daily consumptive use, or about 1.2 inches for a total of 4.8 inches. The average application will be (3.6 + 4.8)/2 = 4.2".

**This column indicates the approximate amount of moisture available between wilting point and field capacity in one foot of soil.

TABLE IX

SUGGESTED MAXIMUM WATER APPLICATION RATES FOR SPRINKLERS FOR AVERAGE SOIL, SLOPE, AND CULTURAL CONDITIONS

Soil Texture and Profile Conditions	Maximum Water Application Rate - Inches Per Hour for Slope and Cultural Conditions and Good Soil Management							
	0-5% Slope w/cover:	Bare	5-8% Slope w/cover:	Bare	8-12% Slope w/cover:	Bare	12% and Over w/cover:	Bare
1. Coarse sandy soils uniform in texture to 6'	2.0	2.0	2.0	1.5	1.5	1.0	1.0	.5
2. Coarse sandy surface soil over more compact subsoils	1.75	1.50	1.25	1.0	1.0	.75	.75	.4
3. Light sandy loams uniform in texture to 6'	1.75	1.0	1.25	.8	1.0	.6	.75	.4
4. Light sandy loams over more compact subsoils	1.25	.75	1.00	.5	.75	.4	.5	.3
5. Silt loams uniform in texture to 6'	1.0	.50	.8	.40	.6	.30	.4	.2
6. Silt loams over more compact subsoil	.6	.3	.5	.25	.4	.15	.3	.10
7. Heavy textured clays or clay loams	.2	.15	.15	.10	.12	.08	.10	.06

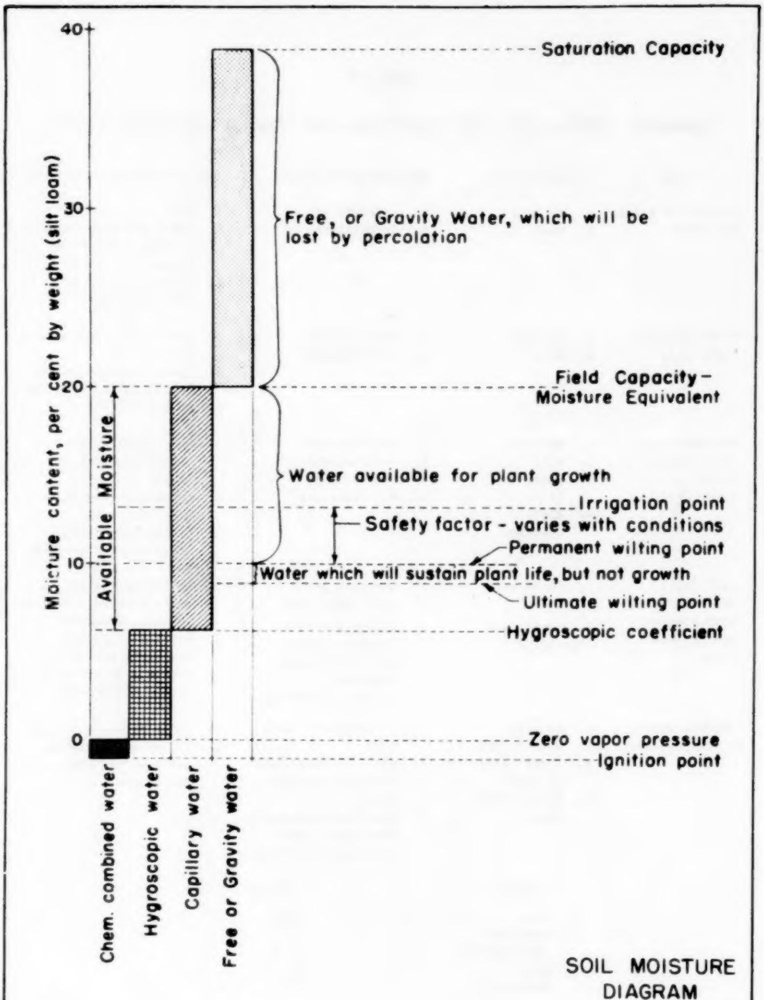
From Soil Conservation Service, Portland, Oregon.

TABLE X

SUMMARY - SPRINKLER TYPE SELECTION FOR COMMON IRRIGATED CROPS

Crop	Conditions	Recommended Type	Special Requirements
Pasture of grass hay crops	1. No wind 2. Wind	1. Intermediate 2. Intermediate	1. None 2. Lower pressure range to keep water drops larger 3. Reduce spacing as wind increases
Alfalfa, grain field peas	1. No wind 2. Wind	1. Intermediate 2. Intermediate	1. Avoid heavy precipitation rates 2. Lower pressure range for larger water drops 3. Reduce spacing
Potatoes, beets, corn, beans, cotton, and truck crops	1. No wind 2. Wind 3. Lands over 3% 4. Rapid coverage	1. Intermediate 2. Intermediate 3. Intermediate 4. High pressure	1. Use higher pressure ranges to break up water 2. Reduce spacing as wind increases 3. Plant rows on cross slope or near contour
Soft fruit, cherries, apricots, peaches, prunes, and plums	1. Lands under 15% 2. Lands over 15%	1. Moderate pressure under tree 2. Low to moderate pressure undertree with single interspace sprinkler settings	1. Select sprinklers on basis of height of trajectory, depending on pruning practices. Staggered sprinkler settings to minimize tree interference
Apples, pears, citrus, avocados	1. No wind 2. Wind problem 3. Steep lands-no wind 4. Steep lands-wind	1. Intermediate overtree 2. Moderate under tree 3. Intermediate overtree 4. Low, moderate undertree and single interspace settings	1. Lower pressure ranges 2. Select sprinkler on basis of trajectory and pruning

Type	P. S. I.
Low	5-15
Moderate	15-30
Intermediate	30-50
High	50-100
Hydraulic	100-


Saturation Capacity
Free, or Gravity Water, which will be lost by percolation
Field Capacity - Moisture Equivalent
Water available for plant growth
Irrigation point
Safety factor - varies with conditions
Permanent wilting point
Water which will sustain plant life, but not growth
Ultimate wilting point
Hygroscopic coefficient
Zero vapor pressure
Ignition point
Moisture content, per cent by weight (silt loam)
Available Moisture
40
30
20
10
0
Chem. combined water
Hygroscopic water
Capillary water
Free or Gravity water
SOIL MOISTURE DIAGRAM
Chart No. I

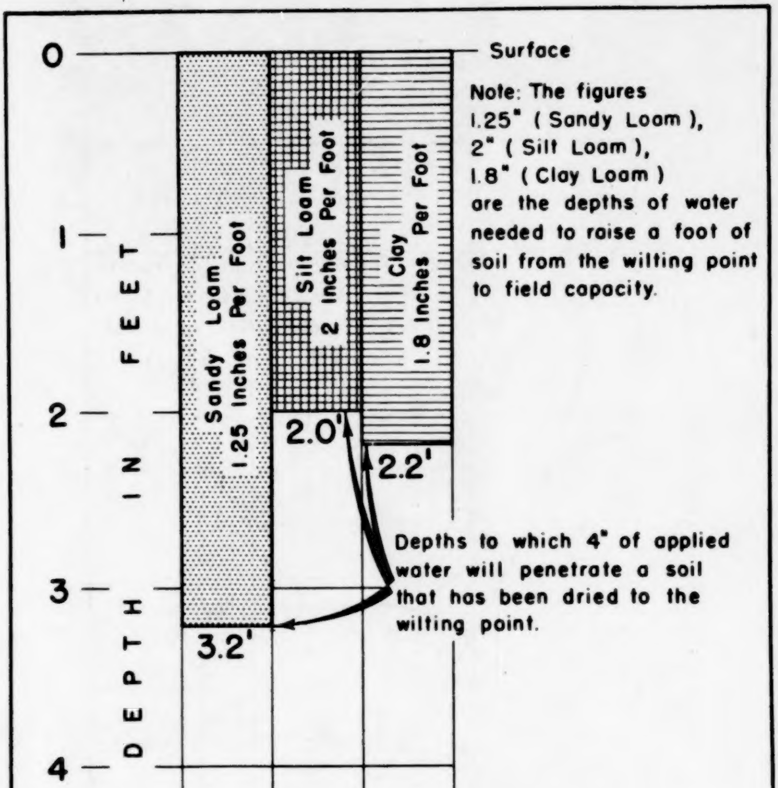
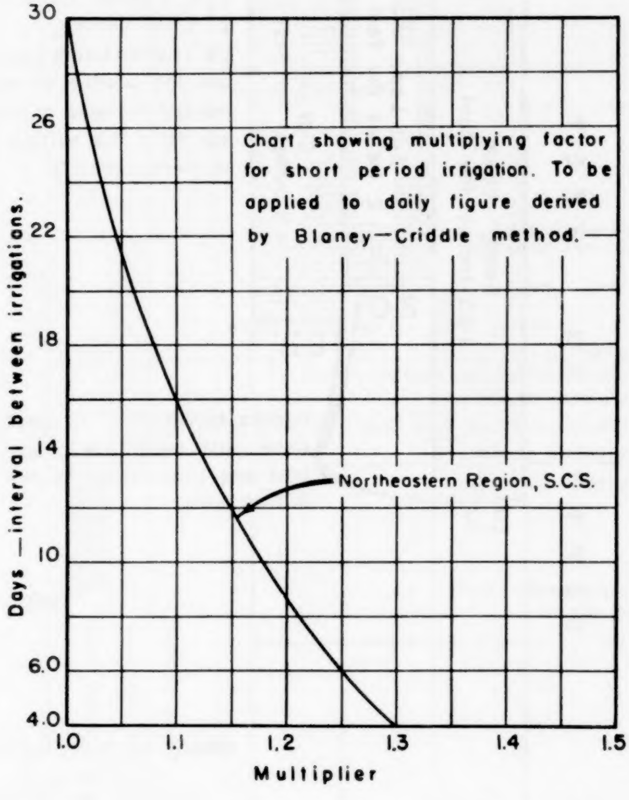


CHART SHOWING DEPTH OF PENETRATION OF SOIL MOISTURE IN A DRY SOIL

Chart No. II



CONSUMPTIVE USE MULTIPLIER

Chart No. III